Transporting the biomass to the power plant required fewer resources and less energy than both feedstock production and power plant operations. Additionally, air and water emissions are lowest from this subsystem. Changing the mode and/or emissions of transportation will not greatly affect the overall impact of this system on the environment.

Apart from the impact soil carbon sequestration has on the carbon closure, biomass yield was found to have the largest effect on the amount of resource consumption, net emissions, and energy use for the system. Changing the amount of fossil fuel used at the plantation and changing the power plant efficiency also had noticeable effects. Most importantly, however, the conclusions drawn remain the same for all sensitivity cases studied. That is, carbon closure and life cycle efficiency are very high for this system. Additionally, the fossil fuel energy ratio does not decrease substantially, indicating that the electric energy the system produces will always be far more than the fossil fuel energy it consumes.

10.0 Future Work

To complement this work, we will extend the life cycle study of biomass processes and expand the developed methodology to other systems. The next set of studies will seek to answer the question of how this process measures up environmentally against fossil-based systems. Life cycle assessments will be performed on three coal-fired power plants, one which incorporates new emissions control technologies, one which meets the New Source Performance Standards, and one which represents a plant in operation today. Another power generation option that is likely to be examined is co-firing of biomass in coal- or oil-fired boilers. This option of retrofitting existing power plants will likely be the first step for utilizing biomass in commercial, large-scale electricity systems. Finally, an assessment of a natural gas-fired IGCC plant may be conducted.

A system similar to that studied in this analysis but which uses other biomass feedstocks may also be examined. An herbaceous feedstock such as switchgrass, a feed from which co-products can be generated, such as alfalfa, and agricultural and forest waste wood are examples.

An interesting extension of this study would be the incorporation of biomass-derived diesel fuels into farming operations. Theoretically, this would close the carbon balance further, although the emissions related to growing biomass would be increased. Additionally, it would be useful to study the environmental effects of biomass crops compared to traditional agriculture crops.

11.0 Related Studies

A brief summary of some of the previous studies that relate to this work is given in this section. Data from many of these studies were used in this assessment, and referenced elsewhere in the text. Although this list is not all-inclusive, it serves to illustrate the nature of past efforts.

DynCorp EENSP, Inc. (1995).	A life cycle assessment of CO_2 and methane emissions from different renewable and non-renewable technologies, including a slightly different version of the same biomass technology assessed here. Energy use and other stressors were not assessed. Emissions factors from a modified version of the TEMIS model was used. Different capacity addition scenarios were addressed.
Ellington and Meo, 1990-91, 1993	A life cycle assessment showing the carbon dioxide emissions from using biomass from tree farms to produce methanol for reformulated gasoline. Presented a useful means of tracking the accumulated amount of CO_2 in the atmosphere. Did not include power production as a use for the biomass.
Graham et al (1992)	Assessment of the CO_2 released in producing biomass in a specific short rotation woody crop scenario. Contains a cursory glance at what the net CO_2 would be for different uses of the biomass. Did not include all upstream processes and transportation. However, the CO_2 released in producing biomass was found to be very close to that reported for the current study.
Gustavsson et al (1996)	Assumed that the only CO_2 inputs into the process were from energy use, and could thus be displaced with biomass-based products. Did not include the upstream processes that use fossil fuels as chemical inputs. CO_2 was the only stressor studied.
OTA Background Paper (1993)	Cursory discussion of the issues involved in establishing bioenergy in the U.S. Does not report an analysis.
Perlack et al (1992)	Excellent source of information on the environmental consequences of producing biomass fuel. According to ORNL, however, some data are now outdated given experience gained in the last few years. Did not discuss upstream processes.
Pimentel et al (1981)	General approach taken to evaluate the energy balance of producing energy from crop and forest residues. Few environmental effects discussed.

Ranney and Mann (1994)	Good summary of what has been learned about the environmental impacts of growing biomass. Issues discussed include previous land use, farm chemical requirements and fates, water quality, air emissions, sustainability, and biodiversity.
Ranney *et al* (1991)	Assessment of the total carbon flows involved in producing biomass as a fuel. Very useful discussion on how above- and below-ground biomass will affect soil carbon. Some data are now considered to be outdated.
Schlamadinger and Marland, 1996	A life cycle assessment showing the carbon dioxide emissions from using conventional and short-rotation forestry to produce biofuels and long- and short-term wood products to displace fossil fuels. Showed cumulative benefits over periods of time ranging from zero to 100 years. Did not include upstream processes or power production as a use for the biomass.
Turhollow and Perlack, 1991	An analysis of the CO_2 emissions from biomass and fossil fuels. Based on conversion factors for each technology. Does not include upstream processes. Assumptions on farming inputs are now considered by ORNL to be outdated.

12.0 Acknowledgments

We would like to acknowledge the Department of Energy's Biomass Power Program for funding this work, and Dr. Richard Bain, Dr. Ralph Overend and Kevin Craig for extensive technical guidance and review. Also, our thanks to the many people outside of NREL who have contributed their time and effort in assisting us, specifically, Bruce Vigon of Battelle for providing ideas on how best to conduct this study, ORNL's Environmental Sciences Division for supplying an extensive amount of information on the logistics and environmental consequences of producing biomass as a dedicated energy crop, and Vince Camobreco of Ecobalance for his many hours of technical support for the TEAM and TEAM Plus software.